MATTSON & SPONSLER

Carbon Dioxide Determination in the Heine Boiler and its Relation to Efficiency

Mechanical Engineering

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CARBON DIOXIDE DETERMINATION IN THE HEINE BOILER AND ITS RELATION TO EFFICIENCY

BY

EARL N MATTSON
AND
JOHN McCLURE SPONSLER

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Earl N. Mattson and John McClure Spensler

ENTITLED Carbon Dioxide Determination in the Heine Boiler

and Its Relation to Efficiency

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in

Mechanical Engineering.

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HEAD OF DEPARTMENT OF Mechanical Engineering.

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PREFACE.

The writers chose the subject under consideration from a desire to collect and present information concerning boiler performance and the relation thereto of the CO_2 content of the flue gases, such information to be obtained from previous tests as well as from tests conducted by themselves. It is believed that a compilation and analysis of data relative to this subject will be of benefit to owners of commercial power plants.

INTRODUCTION.

The object of this thesis is (1) to study boiler efficiency under certain conditions; (2) to determine the percentage of CO_2 in the flue gas at various points in its passage through a setting; (3) to show how the CO_2 content may be used as an index to boiler efficiency.

The tests were conducted on a 210 h.p. Heine boiler in the Mechanical Engineering Laboratory at the University of Illinois. The principal items determined were the efficiencies and the percent of CO_2 at various points through the setting. The draft over the fire and the thickness of the fire were varied for the different tests in order to maintain as nearly as possible the rated capacity of the boiler.

CHAPTER I.

CO_2 RECORDERS.

In good power plant operation it is in general necessary to maintain a high percentage of CO_2 in the flue gases in order that high efficiency may be obtained in the process of heat transmission. There are various types of instruments used for determining the percent of CO_2, which, if their use is properly understood, may be of very great service. There has however, been a great deal of dissatisfaction in their operation as many are unreliable and all require considerable attention.

Apparatus for determining the percentage of CO_2 in flue gas are of two general types, those operated by hand and those that are automatic in their operation. Each type has its advantages and disadvantages, the conditions under which it is to be used determining to a large extent the type most suitable..

HAND ANALYZERS.

The apparatus used for volumetric gas analysis by Elliot, Wilson, Hempel and Orsat are the best known of the hand analyzers. The principle of operation is similar for all. The apparatus consists of a measuring tube, into which the volume of gas can be drawn and accurately measured at a constant temperature and pressure, and a treating tube into which the gases are introduced and brought in contact with various reagents.

There are three reagents commonly employed. The first is a 33% solution of KOH which absorbs CO_2, the second is a solution of pyrogallic acid and KOH which absorbs O, and the third is an ammonical solution of cuprous chloride which absorbs CO.

In making an analysis the gas is drawn into the measuring tube at atmospheric pressure and 100 c.c. retained. This gas is then run into the treating tube and comes into contact with the first reagent. The gas is then returned into the retaining vessel and the amount that has been absorbed is measured. After repeating this process until no further change in volume is observed the gas is run into contact with the second reagent and the process repeated. To make a complete analysis requires about 15 minutes.

This type of instrument has the great disadvantage that it requires so much time to operate it. An engineer or fireman does not have time to do this work and in most cases, unless there is someone whose duty it is to analyze the gas, it probably will not be done.

Hand analyzers are easy to operate, are very reliable and accurate and do not get out of order very readily. They are very convenient as they are small and can be carried to any place a sample is desired. They are the only instruments with which a complete analysis of the gas may be made and this is often very desirable. Their first cost is nominal.

AUTOMATIC CO_2 RECORDERS.

The automatic CO_2 recorders and indicators work on the same principle as the hand analyzers, that is, the CO_2 is absorbed from the flue gas by caustic potash and the remaining quantity of gas is then measured. In these instruments the flue gas is drawn through by an aspirator, or by some other means, and the whole operation becomes automatic.

There are three general types of automatic recorders: (1) those in which the volume of the CO_2 is measured by the difference in pressure after the CO_2 has been absorbed: (2) those in which the caustic potash solution is displaced by a known quantity of the flue gas: (3) those in which a known quantity of the gas is forced through the reagent and the remainder of the gas is then measured.

The Uehling Gas Composimeter is taken as an example of the first type. The principle and method of operation is shown below.

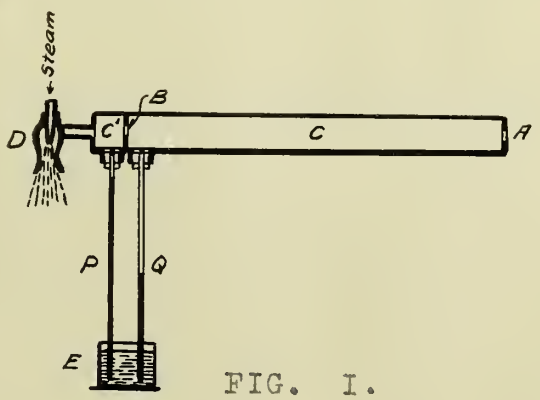


FIG. I.

Referring to Fig. I, C and C^1 are two chambers which are in communication with each other through the aperture B and with the source of gas through the aperture A. C^1 is connected

with an aspirator D as shown. The manometers P and Q indicate the gas tension within the respective chambers. If the aspirator is set in action a vacuum is created in Chamber C^1, the gas will flow through B from Chamber C, causing gas to enter at A, thus establishing a continuous flow of gas through both apertures. If a constant vacuum is maintained in C^1 and the two apertures are of the same size and are maintained at the same temperature, the manometer P will show about one-half the vacuum maintained in C^1, due to the fact that the apertures oppose equal resistance to the passage of the gas. Now if a part of the gas, as the CO_2, be absorbed from the gas in passing through the chamber C the vacuum there will be correspondingly increased. This increase of vacuum in C indicated by the manometer P therefore correctly indicates the volume of the gas absorbed.

The disadvantages of this type of instrument are (1) that both apertures must be maintained at a constant temperature; (2) that they must be kept perfectly clean; (3) that the CO_2 must be completely absorbed while the gas is passing through the chamber C.

The second type of instrument is well represented by the Sarco Automatic CO_2 recorder, Fig.II. In this type the flue gas is drawn into a graduated cylinder, by an aspirator, displacing the caustic potash. During this operation the CO_2 is absorbed and the potash being forced into another vessel actuates the recording pencil motion by means of a float. Thus it is seen that the magnitude of the pencil motion is

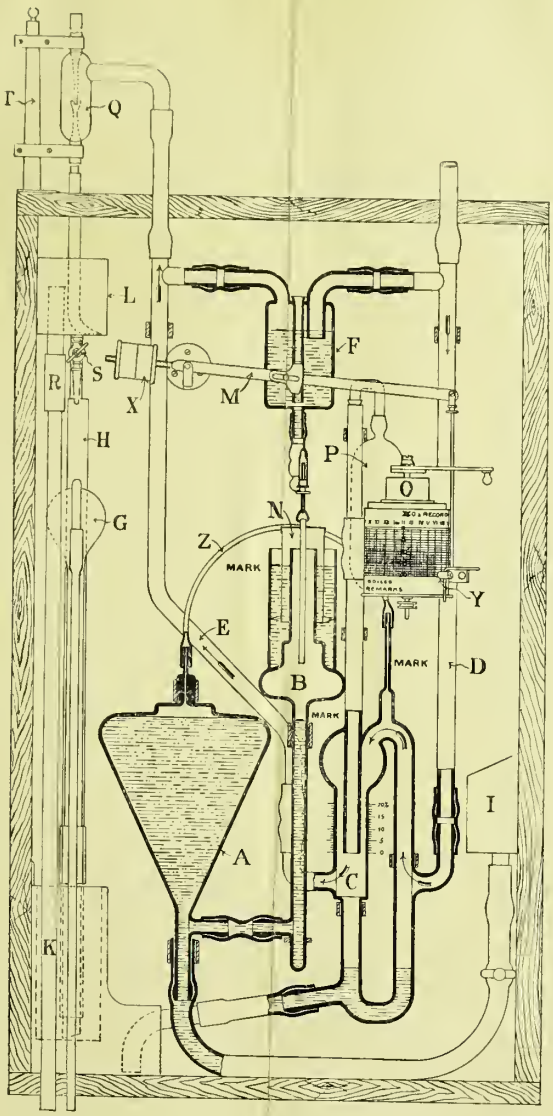


FIG 2.—Sectional Elevation.

Fig. II.
SARCO RECORDER.

proportional to the amount of potash solution displaced.

This type has the advantages incident to the automatic recorders. Its disadvantages are: (1) there is a constant menance of the potash crystallizing and clinging to the balanced parts that move up and down and make the record, thus throwing them out of balance and causing error; (2) the unavoidable variations in temperature to which every CO_2 recorder is subject, supplies another disturbing variant in machines where the volume of the potash solution is relied upon for measuring the volume of the gas.

PRECISION INSTRUMENT COMPANY

(*a*) Siphon tank.
(*b*) Float.
(*c*) Chain.
(*d*) Extractor.
(*e*) Drip valve (water)
(*f*) Water feed.
(*g*) Siphon tube.
(*h*) Balance valve or change-over cock.
(*j*) Recorder bell and tank.
(*k*) Water tank.
(*l*) Overflow from KOH tank.
(*m*) Caustic potash (KOH) vessel.
(*n*) Scale.
(*o*) Overflow pipe.
(*p*) Flue gas inlet.
(p_1) Inlet for constant stream of gas.
(*q*) Balance weight.
(*s*) Suspension balance.
(*x*) Water inlet (furnishing motive power for the recorder and also drawing continuous stream of flue gas through p_1).
(*y*) Waste water outlet.

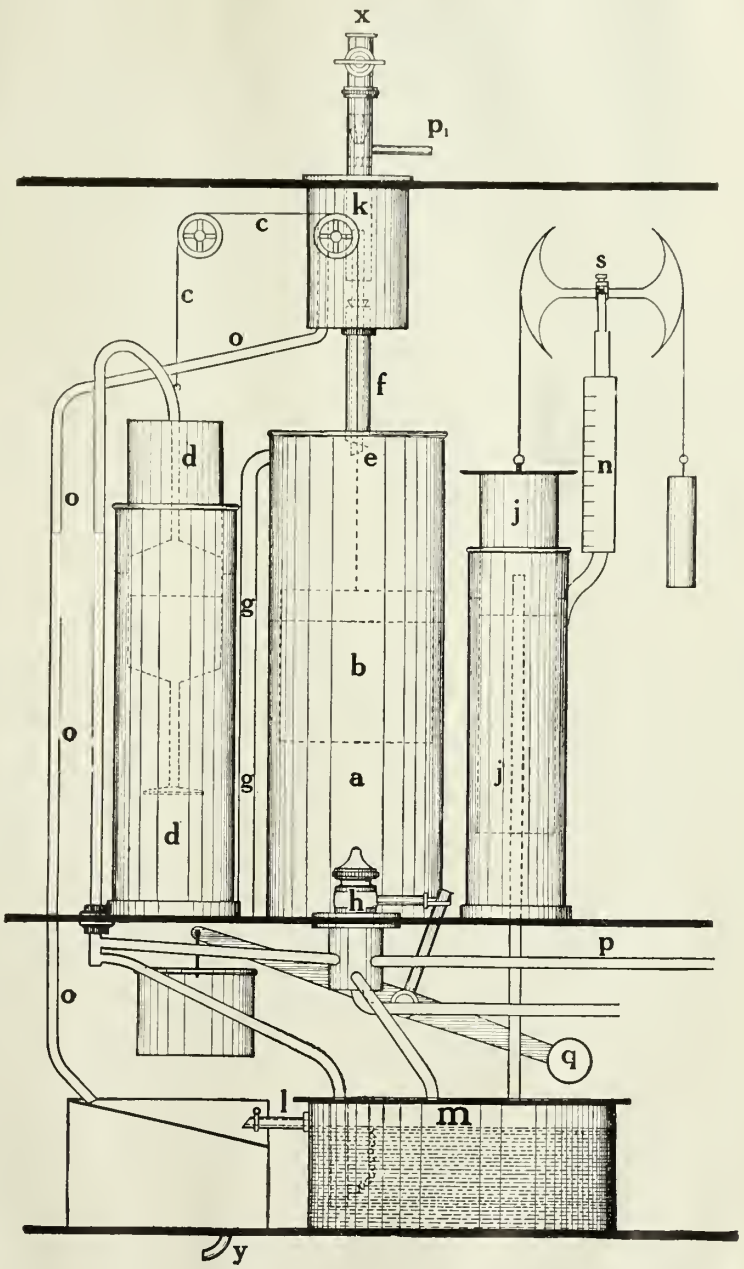


Fig. III

Precision Simmance-Abady CO_2 Recorder

This sketch shows the whole of the working parts in position except the clock and pen, and illustrates the extreme simplicity of the instrument.

Water is put into vessels (*d*) and (*j*) and caustic potash (KOH) into (*m*).

CO_2MBUSTION RECORDER

Fig. III.

The action of the third type is shown by a description of the Precision instrument, Fig. III. In this machine a known quantity of gas is drawn into a vessel, from which the water is drawn by siphon action. The gas is then forced through a caustic potash solution, which absorbs the CO_2, into a water sealed bell which is graduated and attached to the pencil motion. This bell will be raised an amount proportional to the amount of gas forced under it and the magnitude of the pencil motion will therefore be determined by the amount of CO_2 in the gas.

The quantity of gas absorbed, which represents the percentage of CO_2, is determined and recorded on a diagram by means of vertical lines. This process is repeated about every five minutes. The top of the various lines form a curve which shows the fluctuations of the percentage of CO_2 in the flue gases during the time the recorder has been working.

The advantages of this type are: (1) that it does not depend upon the density of the potash solution for its accurateness; (2) that temperature will not effect the mechanism; (3) that the solution does not come into contact with any of the balanced parts of the machine.

ADVANTAGES AND DISADVANTAGES OF CO_2 RECORDERS.

The disadvantages of the Automatic CO_2 recorders are: (1) that it is hard to keep the pipes leading to the boilers absolutely air tight, as is necessary for these instruments; (2) there is a great deal of trouble caused by dust. However,

this can be overcome by installing a good filter, which is shown later.

The advantages of these instruments as given in the Engineer for Jan. 27, 1911, are: (1) that it shows at any and all times the percentage of CO_2 being obtained, so giving a guide to engineers in charge and to firemen as to the conditions prevailing in the furnace; (2) it is an index to the correct thickness of fire under different conditions; (3) it is a guide as to the varying amount of draft to be given to the fires under varying conditions; (4) it is an index of any air leakage at all points between the furnaces and the flues from which the gas for the analysis is taken.

FILTERS.

A good practical filter is shown in the following illustration. This filter is put out by the Precision Instrument Company and removes the dust and condensation from the gases before they can do any damage by choking up the pipes and instrument. One of the simpler forms of filter is made by putting a piece of 2" pipe about 2 ft. long in the line leading to the instrument and filling this with cotton.

Dust Filter and Connections for Precision Simmance-Abady CO_2 Recorder

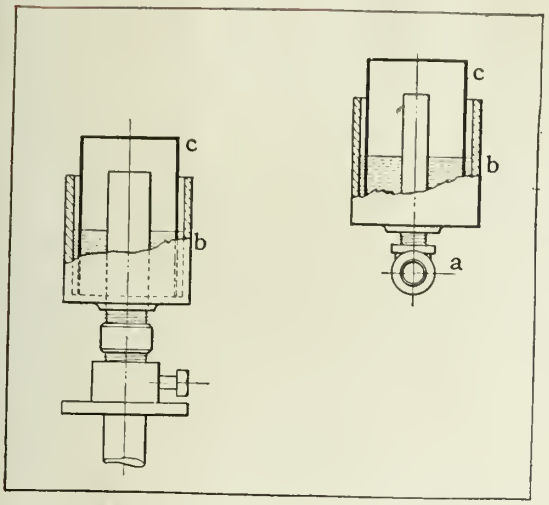


Fig. 2. Boiler shut off from CO_2 Recorder by caps (*c*) in oil cups (*b*) on boiler "offtake" and "bus" pipe (*a*).

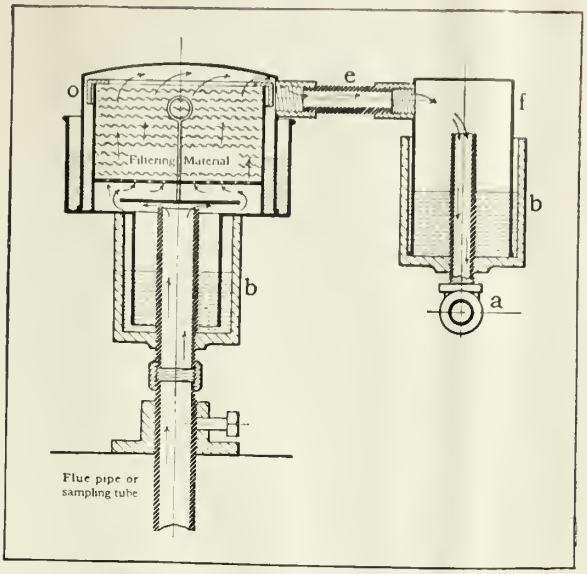


Fig. 3. Boiler connected to CO_2 Recorder by removing caps (*c*) and inserting filter (*o*) and cover (*f*) in the oil cups (*b*), and coupling pipe in flue to "bus" pipe (*a*).

FIG. IV.

CO_2 RECORDERS IN POWER PLANTS.

It has been proven by the successful operation of a large number of installations that the CO_2 recorder is very useful in building up and maintaining a high efficiency in a power plant. In some cases it has been possible to cut down the coal consumption of the plant as much as 20 to 25 percent.

The automatic recorder is the best instrument to use for maintaining a high efficiency, because it gives a continuous record of the CO_2 percent. Suppose it has been learned by experiment that certain combinations of furnace conditions, as draft, thickness of fire, etc., will carry the load and give the highest obtainable efficiency under the circumstances,

showing a certain percent of CO_2 in the flue gases, then the fireman may be given orders not to allow the percent of CO_2 to fall below this amount. The CO_2 recorder will show the amount that has been obtained during the day, and if it is unsatisfactory the fireman may be called to account for it. A bonus system bases upon the CO_2 recorder may be used.

The efficiency may best be built up by the hand analyzers. They are better adapted for determining air leakage and the best furnace conditions, and also because of their reliability and accurateness they should be used as a check on the recorders.

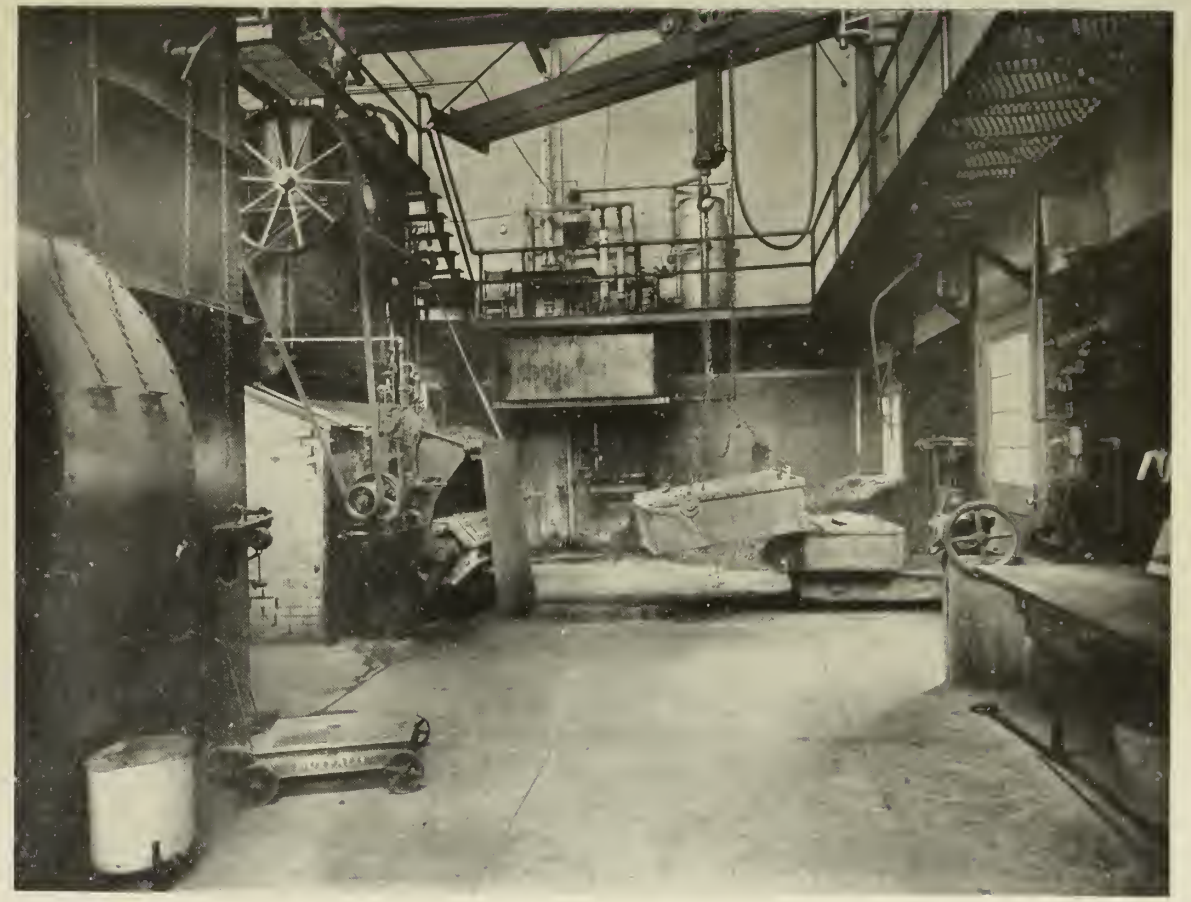
CHAPTER II.

DESCRIPTION OF APPARATUS.

The boiler used during the tests reported in this thesis was a 210 h.p. Heine water tube boiler the principle dimensions of which are given below in Table I.

TABLE I.

Kind of boiler,	210.h.p. Heine water tube.
Kind of furnace,	Green chain grate
Width of grate, inches,	54
Length of grate, inches,	102
Grate surface, sq. ft.,	38.25
Area of chimney, sq. ft.,	8.7
Height of chimney above grate, feet,	45,5
Kind of draft,	Induced
Water heating surface, sq. ft.,	2027.0
Number of tubes,	116.
Diam. of tubes. outside, inches,	3.5
Ratio of water heating surface to grate surface,	53.1 to 1



GENERAL VIEW OF TESTING PLANT

FIG. V.

Simultaneously with the tests for the CO_2 determinations others were made to determine the effect of a Sturtevant economizer upon the efficiency of the boiler, and for this reason alternate tests were made with and without the economizer. No discussion of the results obtained concerning the economizer will be given in this paper. Fig. V. gives a view of the front of the boiler showing the economizer, water weighing tanks, ash and coal cars, hoists and scales.

CHAPTER III.

METHODS OF TESTING.

The tests were run in accordance with the code of the A.S.M.E., employing the alternate method of starting and stopping.

The coal used was 1 1/4 inch screenings from Vermillion County, Illinois. This was weighed out in 500 lb. lots and fed to the furnace as needed.

The ashes were removed by means of an air hoist, as required.

A small shovelfull of the coal and ashes were taken from each lot and put into large cans. At the end of the test this was pulverized and quartered until there was only enough to fill a quart jar. These jars were filled and sealed and sent to the chemist who made an approximate analysis of each sample and one ultimate analysis of the coal from a composite sample.

The water fed to the boiler was weighed in tanks and pumped into the boiler by means of a steam pump. A feed water

recorder was used, which gave a check on the number of tanks dumped.

A meter was used to measure the water passing through the water-back.

The quality of steam was determined by a throttling calorimeter and the required temperatures, pressures, and drafts were determined by the usual means.

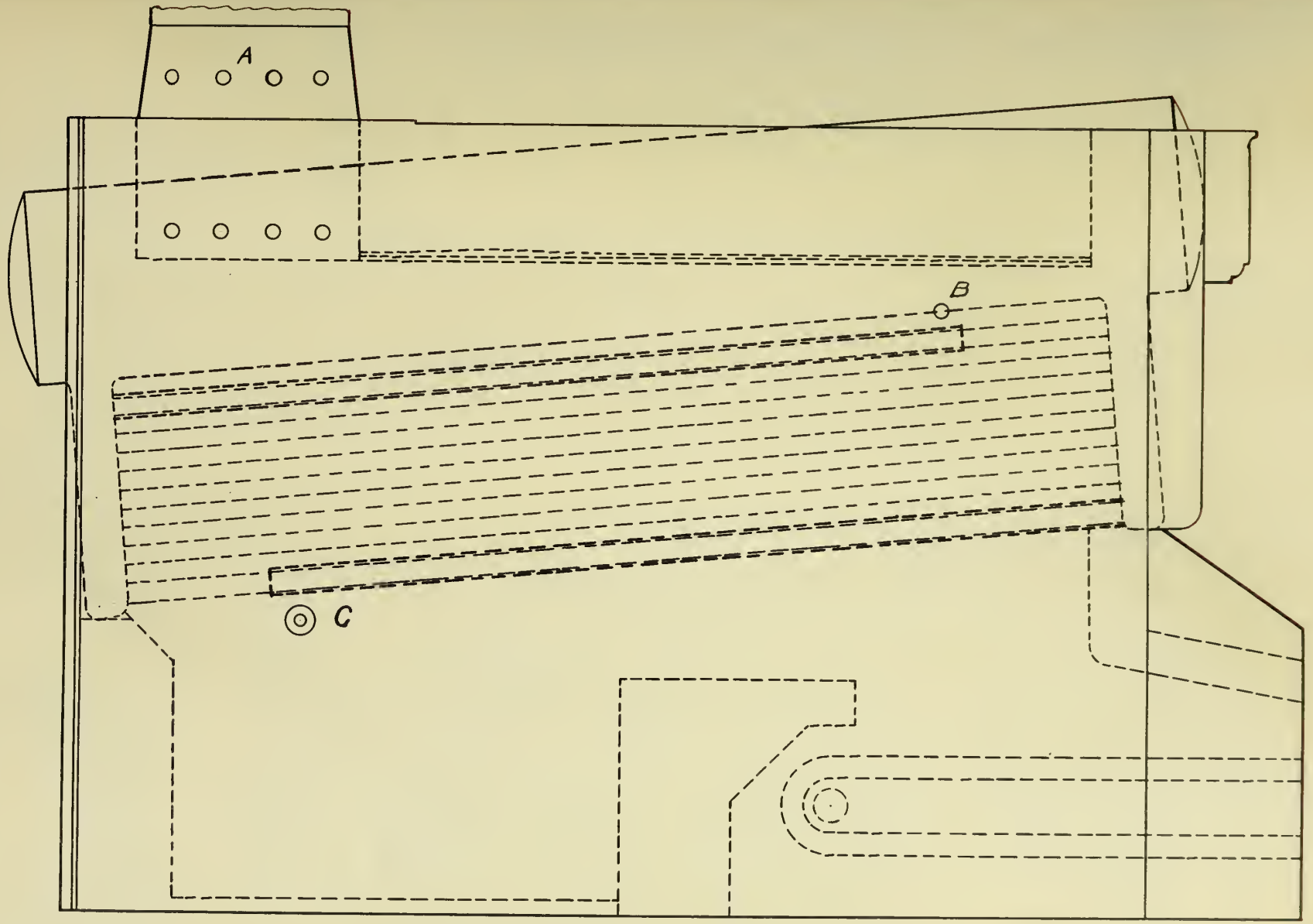
The instruments used were calibrated and found to be satisfactorily accurate.

Readings were taken every fifteen minutes.

FLUE GAS.

Samples of the flue gas were taken at three different places, namely, in the breeching, at the front end of the boiler as the gases start on their last pass to the flue and in the combustion chamber. The location of these points are shown at A, B and C, Fig.VI. The sample from the breeching was taken by four separate sampling tubes which led to a junction box, from which one hour samples were drawn into a large bottle by water displacement. By this means, a good average sample could be obtained.

In the front end of the boiler only one tube was used. This was made of 1/2" pipe with small holes drilled about 6" apart on different sides of the pipe, which served as intakes for the gas sample. The end was closed and one hour samples were taken here in the same manner as described above.



HEINE BOILER AT ENG. EXP. STATION
UNIV. OF ILL. Fig. VI.

The same kind of tube was used in taking samples from the combustion chamber, but here the high temperature made it necessary to take snap samples. This method was not as satisfactory as the others, but as the samples were taken every half hour the results were considered to be a good average of the entire test.

The Orsat apparatus was used for the analyses.

PRELIMINARY TESTS.

Eight preliminary tests of four hours each were run. It was intended to use the results from these tests but they were found to be unsatisfactory due to the fact that not enough time was allowed to get the fire into good condition and the setting properly warmed before starting the test.

As tests were being run at the same time to find the increase of plant efficiency when an economizer was used, a Sturtevant economizer was turned in during the morning tests and was taken out during the afternoon tests. When the calculations were made it was found that there was a higher plant efficiency when the economizer was not used. This can be explained by the fact that the tests were started too soon after the banks were removed from the fire. Thus fire conditions and furnace conditions for any one test were not comparable with those of the other tests or with previous tests.

The flue gas analysis also indicated the higher efficiency in the afternoon tests as the percentage of CO_2 was considerably higher than in the morning tests.

In these tests an attempt was made to change the draft without changing the thickness of the fire. This in one case caused very poor combustion because of an insufficient air supply and gave an efficiency of about 45%, while in another case when the draft was increased the fire was blown to pieces.

FINAL TESTS.

When the poor results from the four hour tests were discovered, four tests of ten hours each were run. For these tests the fire was built up several hours before the beginning of the test, from the fire which had been banked over night, until the boiler was developing approximately its rated capacity. During these tests the thickness of the fire was changed with the draft so that a good fire was maintained, Other conditions were kept constant as nearly as possible.

CHAPTER IV.

THEORETICAL DISCUSSION OF EFFICIENCY OF COMBUSTION.

In a discussion of the efficiency of combustion of coal in a boiler furnace it is desirable to first see the theoretical efficiency which may be obtained and then compare that with the results of the actual test.

Coal is a hydrocarbon, consisting mainly of volatile combustible matter, carbon, hydrogen, ash and sulphur. When coal is burned the volatile matter is first driven off as gases, absorbing heat in the process of gasification. If the air necessary for combustion is supplied the carbon driven off

will unite with oxygen forming CO_2 directly, or first forming CO and then CO_2. When the carbon unites with oxygen to form CO_2 the greatest yield of heat possible from the coal will be given off. CO_2 will, however, if exposed to carbon in a heated state, absorb another atom of carbon and become converted back into CO, which action is a reducing one and absorbs about 6688 B.t.u. per lb. of carbon. In addition to this, carbon which would otherwise be used in the process of combustion is consumed by this reduction as shown in the formula.

$$CO_2 + C = 2\ CO.$$

In the process of combustion in the boiler furnace we may consider that the coal is composed only of carbon which will unite with oxygen in the proportion as shown in the equation

$$C + O_2 = CO_2$$

$$12 + 32 = 44$$

$$1 + 2\ 2/3 = 3\ 2/3 \text{ by weight}$$

$$1 + 1 = 1 \text{ by volume}$$

From this it is seen that one pound of carbon requires 2 2/3 lb. of oxygen in order to burn to CO_2. Also that the volume of the products of combustion is equal to the volume of the oxygen. Since there is 23% of oxygen in the air, by weight, we may consider that there is 77% of nitrogen. Then the weight of the products of combustion will be

$$\frac{2.666}{.23} + 1 = 12.58\#$$

Now there is 21% of oxygen in the air by volume and since the volume of the CO_2 remains the same as the volume of oxygen

it is seen that the maximum percent of CO_2 theoretically obtainable will be 21%. The remaining 79% will be nitrogen which in passing through the furnace absorbs a large amount of heat and carries it away through the stack. Considering 21% of CO_2 formed we see that for an average stack temperature of 500° F., and considering that there are 14600 B.t.u. given off per lb. of carbon, that the average specific heat of the flue gases is .24 and that the temperature of the outside air is 60° F., we get

$$12.58 \times .24 \times 440 = 1330 \text{ B.t.u.}$$

which is carried away by the flue gases per lb. of carbon burned. This is equal to $\frac{1330}{14600} = 9.1\%$ of the heating value of the carbon. It will be noticed here that this much must always be lost in the chimney.

It is not practicable in any furnace to burn coal without using excess air in order to obtain complete combustion. In good average practice the actual amount of air used is probably 40 to 100% greater than that theoretically required. Using double the required amount of air there will then be 23.16 lb. gas per lb. of carbon and the heat lost in the flue gases will be

$$\frac{24.16 \times .24 \times 440}{14600} = 17.45\%$$

There are several other losses in the boiler all of which are fairly constant and a good average value given by Gebhart, Page 33, is 12%. The following are the itemized losses:

Loss due to carbon burning to CO	1%
Loss of fuel through grate	1%
Loss due to moisture in coal Loss due to H in coal Loss due to moisture in air	3%
Loss due to smoke and soot	0.5%
Loss due to radiation	6.5%
	12.0%

This together with the loss in the chimney gases for the following different percentages of CO_2 was used in constructing the curve No. 1, Fig. VII which shows the theoretical efficiency of the boiler for percentages of CO_2 ranging from 5%, which is about as low as is ever found in poor practice, to 15%, which is all that can be expected under the best conditions. The chimney loss for the different percentages is calculated as follows: Consider that there might have been 21% of CO_2 formed and only 5% was found. Then it is evident that there must have been $\frac{21}{5}$ excess air.

Then $\frac{21}{5} \times 11.58 = 48.7\#$ air

$$\frac{49.7 \times .24 \times 440}{14600} = 35.95\%$$

$35.95 + 12 = 47.95\%$

$100 - 47.95 = 52.05\%$ eff.

TABLE II.

TABLE OF THEORETICAL BOILER EFFICIENCIES.

$\%CO_2$	Eff.%	$\%CO_2$	Eff.%
5	52.05	11	71.00
6	58.00	12	72.63
7	62.72	13	73.75
8	65.30	14	74.40
9	67.75	15	75.55
10	69.70	16	76.27

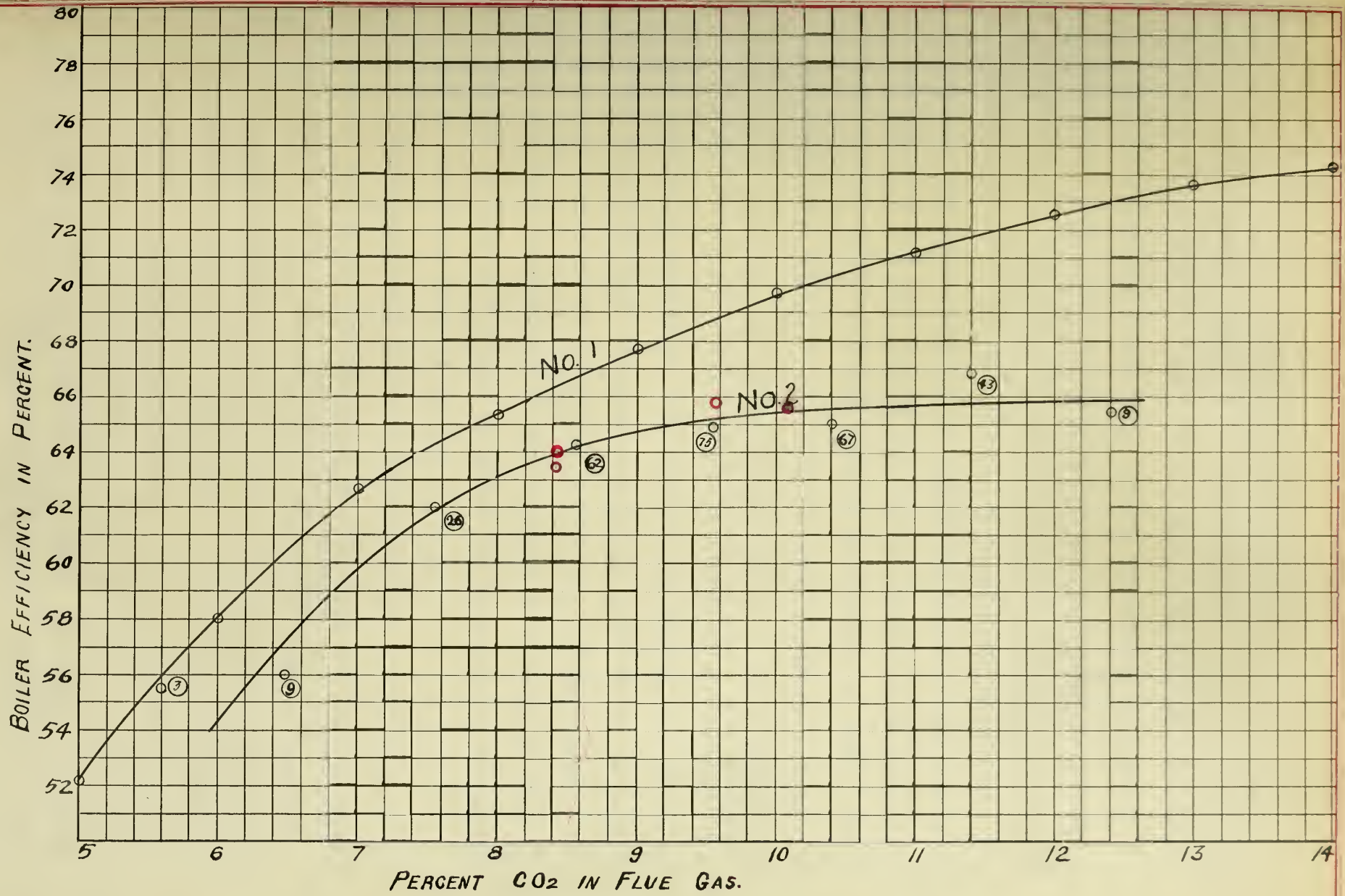

BOILER EFFICIENCY IN PERCENT.
80
78
76
74
72
70
68
66
64
62
60
58
56
54
52
NO. 1
NO. 2
3
9
26
62
75
67
43
5
5
6
7
8
9
10
11
12
13
14
PERCENT CO2 IN FLUE GAS.

Fig. VII.

DISCUSSION OF EFFICIENCY

Curve No. 2, Fig. VII, was obtained from a series of 293 tests made for the United States geological survey at the fuel testing plant, St. Louis, Missouri, by Lester P. Breckenridge. The average efficiency and percent of CO_2 for groups of tests, the number in the circle denoting how many there were in each group, were plotted as shown. This curve lies approximately 3% below the theoretical curve up to about 9 percent, where the curves commence to diverge, the latter curve becoming nearly horizontal at 66%. It is evident that when the CO_2 content reaches 9% only about 1% more efficiency - at the most only 2% - is to be gained by raising it higher. This small increase in efficiency is not so decidedly marked on the theoretical curve, but it is seen from Table II that furnace conditions grow worse in a geometrical ratio of progression as the CO_2 is decreased. Thus we see that theoretically an increase from 5 to 6% CO_2 would result in nearly 4 times as great an increase of efficiency, as an increase from 11 to 12% of CO_2.

There are many factors effecting the efficiency of a boiler for which the analysis of the flue gas may be used as an index. The building up of boiler efficiency requires considerable time, patience, and above all good engineering judgment. One of the first steps for this purpose is the determination of the air leakage, an item which is of much more importance than is ordinarily supposed for it often results in a loss of from 3 to 5% of the fuel. The lower pressure inside the setting draws the air in through any cracks there may

be and also through the bricks themselves. Before any relation may be established between CO_2 and efficiency the air leakage must be determined. This can most easily be done by comparing the gas analysis at different points of the boiler. If a very small percent of CO_2 is obtained at the breeching and a much larger percent is obtained in the passes of the boiler, the fact is evident that the gases have been diluted by air leaking into the boiler. This represents a loss, for this air is raised in temperature and then passes up the flue carrying away the heat. A large amount of air might leak into the breeching just below the sampling tube, as is often the case for the joints between the breeching and setting are sometimes very bad, and a small percentage of CO_2 would result, but the boiler efficiency would not be decreased. Analysis at the furnace expresses furnace efficiency while analysis at the breeching expresses furnace efficiency minus the effect of air dilution posterior to the furnace.

If in testing a boiler for air leakage it is found to be large, steps should be taken to remedy it. All holes should be stopped up with some fireproof material. A good scheme, is to "size" the boiler with glue and cover this with a few coats of fireproof paint. This will prevent the air filtering through the bricks. The effect of merely filling the holes is shown by the fact that the difference in the CO_2 percentage between the breeching and the point B, Fig. VI. page 17 was decreased one percent. when the top of the boiler was plastered with an

asbestos paste during the preliminary tests. The amount of air leakage through the brick was brought out by accident. A sampling tube was supposed to have been inserted for a sample at point B, but instead of that a nipple was merely screwed in. The gas analysis showed only about 3% when 6% was being obtained at the breeching. The air leaking through the brick collected in this pocket in the wall and this air was what was mostly drawn out and analyzed.

After the air leakage has been determined and remedied the amount of excess air being supplied may be determined. The importance of this has already been pointed out. A very careful study of the furnace operation is necessary to determine the greatest percent of CO_2 obtainable, which under good conditions may run up to 12 percent. The amount of draft is the principal item effecting this. As a general proposition the least draft that can be used to carry the load is the best for the coal pile, but this is not true always for the draft may be reduced so much that CO is formed with the resulting waste. It is known that the higher the velocity of the gas and the thinner the fuel bed, the less will be the percentage of CO formed. A heavy fuel bed would therefore favor the formation of CO and the greater the supply of air to a given depth of bed the less should be the tendency to form CO. The draft that is the best should give the highest percentage of CO_2 and the lowest of CO.

To determine the best draft a hand sampling apparatus should be used. By taking gas analysis and changing the draft the increase of CO_2 may be noted and the maximum obtained.

Care should be taken that all other conditions should be the same in this test.

In connection with the determination of the best draft it may be advisable to test for the most advantageous thickness of fire. This may often bring the percentage of CO_2 up to the desired amount when changes in the draft will not accomplish that end.

In a similar manner gas analysis instruments may be used for solving various other questions concerning the operation of the furnace. There has always been more or less disagreement as to the best method of firing. Each furnace has its own peculiarities and the engineer should adapt his method of firing to suit these. He may also determine whether his coal should be wet or dry for the greatest economy and in fact almost anything he wishes to know about his furnace may be determined by a systematic application of the flue gas analysis.

CHAPTER V.

DATA AND RESULTS.

Table No. III shows the relation between flue gas analysis at different points in the boiler, draft, thickness of fire and efficiency.

Table No. IV presents the results obtained from the four ten hour tests.

The results were calculated according to the A.S.M.E. Code, the methods of which are considered as standard. For the tests when the economizer was in operation, boiler efficiency "without economizer" was calculated by making use of the temperature of the feed water as it left the economizer and entered the boiler.

TABLE III.

Date of Test	Analysis of Flue Gas, Percent									Draft over fire, inches of water	Thickness of fire, inches	Efficiency of Boiler, Percent
	Position of Sampling Tube											
	Front End of Boiler			Combustion Chamber			Breeching					
	CO_2	O	CO	CO_2	O	CO	CO_2	O	CO			
March 28 1912	8.43	10.91	0	7.07	11.93	0	6.87	12.54	0	0.2	4.5	64.0
March 29 1912	8.41	10.62	0	7.7	11.96	0	6.52	12.92	0	0.19	4.5	[Without Econ. 63.4] 69.1
March 30 1912	9.58	9.29	0	9.0	10.25	0	7.57	11.58	0	0.15	5.0	65.8
March 31 1912	10.1	8.8	0	8.6	10.9	0	6.8	12.7	0	0.15	5.5	[Without Econ. 65.5] 71.6

TABLE II
DATA AND RESULTS

A.S.M.E. Code No.	Economizer	Out	In	Out	In
	Test Number	1	2	3	4
1	Date of Trial	March 28	March 29	March 30	March 31
2	Duration of Test, Hrs	10	10	10	10
	Average Pressures				
11	Steam pressure, gauge, lbs. per sq. in.	132	132	135	139
12	Force of draft between damper and boiler, inches of water.	.47	.55	.37	.39
13	Force of draft in furnace, inches of water.	.20	.19	.15	.15
	Average Temperatures				
15	Of external air, degrees.	46.3	48.4	51.5	67
16	Of fireroom, degrees.	66.7	68.0	66.0	76.0
20	Of feed water entering [Economizer / boiler], degrees.	60.8	[160.2 / 64.7]	63.4	[63.0 / 76.0]
21	Of escaping gases from boiler, degrees.	530.0	540.0	540.0	525.0
	Fuel				
25	Weight of fuel as fired, lbs.	9836	11212	10463	9591
26	Percent of moisture in coal as fired.	13.72	14.12	14.65	13.04
27	Total weight of dry coal consumed, lbs.	8487	9629	8930	8350
28	Total ash and refuse, lbs.	1972	1957	1888	1924
30	Total combustible consumed, lbs.	6401	7405	6684	6238
31	Percent of ash and refuse in dry coal.	23.3	20.3	21.1	23.06
	Proximate Analysis of Coal as Fired				
32	Fixed carbon, percent.	32.92	33.78	33.39	34.73
33	Volatile matter, percent.	36.60	35.55	35.21	36.15
34	Moisture, percent.	13.72	14.12	14.65	13.04
35	Ash, percent	16.76	16.55	16.75	16.08
	Total, percent.	100.00	100.00	100.00	100.00
36	Sulphur separately determined, percent.	4.78	4.36	4.87	4.26
43	Moisture in air dry sample, percent.	2.30	2.36	2.25	2.32
	Analysis of Ash & Refuse				
44	Carbon, percent.	22.13	18.87	26.16	29.10
45	Earthy matter, percent.	77.84	81.13	73.84	70.77
45(a)	Moisture, percent.	.03	.00	.00	.13
	Total percent	100.00	100.00	100.00	100.00
	Fuel per Hour				
46	Dry coal consumed per hr. lbs.	848.7	962.9	893.0	835.0
48	Dry coal per sq. ft. of grate surface per hr., lbs.	22.15	25.15	23.32	21.8

A.S.M.E Code No.	Economizer	Out	In	Out	In
	Test Number	1	2	3	4
	Calorific Value of Fuel				
50	Calorific value by oxygen calorimeter per lb. of dry coal, B.T.U.	11410	11485	11478	11613
51	Calorific value by oxygen calorimeter per lb. of combustible, B.T.U.	14170	14236	14280	14246
	Quality of Steam.				
54	Percentage of moisture in steam.	2.2	1.6	2.0	2.3
56	Corrected quality of steam, percent.	98.37	98.90	98.51	98.13
	Water				
57	Total weight of water fed to boiler, lbs.	49236	61927	53200	54330
57.1	Corrected weight of water fed to boiler, lbs.	50682	63482	54874	55832
59	Water evaporated corrected for quality of steam, lbs.	49871	62783	54051	54771
60	Factor of evaporation.	1.2	1.097	1.197	1.095
61	Equivalent water evaporated into dry steam from and at 212°	59845	74955	64699	65168
	Water per Hour				
62	Water evaporated per hour corrected for quality of steam, lbs.	4987.1	6278.3	5405.1	5477.1
63	Equivalent evaporation per hr. from and at 212°, lbs.	5984.5	7495.5	6469.9	6516.8
64	Equivalent evaporation per hr. from and at 212° per sq. ft. water heating surface, lbs.	2.95	3.70	3.19	3.21
	Horse Power				
65	Horse power developed – 34½ lbs. of water evaporated per hr. into dry steam from and at 212° equals one horse power.	173.3	217.0	187.3	187.7
66	Builders rated horse power, H.P.	210	210	210	210
67	Percentage of builders rated horse power developed.	82.6	103.4	89.2	89.9
	Economic Results				
68	Water apparently evaporated under actual conditions per lb. of coal as fired, – Item 61 ÷ Item 27 – lbs.	5.13	5.63	5.22	5.80
69	Equivalent evaporation from and at 212° per pd. of coal as fired – Item 61 ÷ Item 27 – lbs.	6.09	6.68	6.18	6.79
70	Equivalent evaporation from and at 212° per pd. of combustible – Item 61 ÷ Item 30 – lbs.	9.35	10.13	9.69	10.45
	Efficiency				
72	Efficiency of the boiler, – heat absorbed by the boiler per lb. of combustible ÷ by the heat value of one lb. combustible, percent Item 70 × 970.4 ÷ Item 51	64.0	"Without Economizer" 63.4 69.1	65.8	"Without Economizer" 65.5 71.6
73	Efficiency of boiler and grate, percent Item 69 × 970.4 ÷ Item 50	60.0	65.8	61.3	65.1

COMPARISON OF DATA.

The efficiencies obtained from the tests agree very closely with those obtained in the tests of the U.S. Geological Survey before mentioned, and represent average practice. The points shown in red, Fig. VII, page 23, were obtained by plotting the efficiencies of the tests without reference to the economizer against the percent of CO_2 at the beginning of the last pass of the boiler.

DISCUSSION OF DATA.

From Table III it is seen that the economizer increased the plant efficiency about 5% when a draft of 0.2 inches of water was used and about 6% under the lighter draft of 0.15. This is hardly as large a saving as is claimed for the economizer but under better installation this could probably be increased. The economizer was placed alongisde the boiler and this necessitated a considerable length of exposed flue from the furnace to the economizer. The temperature of the gases dropped about 100° between the beginning and end of this flue and this drop represents a loss of heat that the economizer might have, if more advantageously installed, made use of.

In the gas analysis the maximum percent of CO_2 was obtained at the point B, Fig. VI, page 17. In the combustion chamber, combustion was not complete, as was shown by the low percent of CO_2 obtained in the gas analysis, also by the fact that it was filled with sparks and flames. The percentage of

CO_2 was less at the breeching than at point B due to air leakage. This air leakage decreased the CO_2 percentage between these two points about 2%. There was no CO found in the sample excepting in a very few instances where slight traces were found.

From Table III it is seen that the efficiency increases with the percent of CO_2. Comparing the tests run with the economizer and those without, it is seen that in the first case for an increase of 1.15 percent CO_2 the efficiency increases 1.8 percent and in the latter case for an increase of 1.59 percent CO_2 there was an increase in efficiency of 2.5 percent. In both cases the draft and thickness of fire were different, which shows that the efficiency may be built up, as before explained, by changing the draft and thickness of fire.

CHAPTER VI.

SUMMARY AND CONCLUSIONS.

From our tests and the others mentioned above it is seen that in general, efficiency increases with the percentage of CO_2 formed during combustion, that the flue gas analysis may be used to build up boiler efficiency and to maintain the efficiency after it has been built up.

The CO_2 recorders or indicators of the continuous type are more adapted for maintining the efficiency, while the hand sampling apparatus, because of its greater reliability, is almost indispensable for a check on the automatic recorder. The hand analyzer is also more convenient for determining air leakage and in addition gives a more complete analysis of the gas.